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Double charmed baryon production at B-factory.

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Abstract
The cross-section for the double charmed baryon production at a B-factory is estimated on the basis of the perturbative QCD calculations for the cc-diquark production as well as of the quark-hadron duality.

1 Introduction

Recently a noticeable progress has been achieved in the study of production, decay and spectroscopy of hadrons, containing two heavy quarks [1-12]. The expected production number of such hadrons with respect to those with a single heavy quark is of the order of $10^{-(3\div 4)}$. For example, at the Z^0-boson pole the number of events with heavy quarks is $\sim 10^6$, consequently the number of hadrons with two heavy quarks is expected to be $\sim 100 - 1000$. Taking into account specific decay modes of hadrons with two heavy quarks one may expect the detection of single events with such hadrons, which makes their observation at LEP problematic.

In this letter we consider the double charmed baryon production ($\Sigma_{cc}^{(*)}$) under the conditions of a B-factory with high luminosity $L = 10^{34}$ cm^{-2}s^{-1}, where the number of $\Sigma_{cc}^{(*)}$ is by two orders of magnitude greater than at the Z^0-boson pole.

2 Fragmentation mechanism

In the recent paper [12] the authors have estimated the production of Σ_{cc}-, Σ_{bc}-, Σ_{bb}-, Λ_{bc}-baryons in the region of the heavy quark fragmentation at high energies. These estimations are based on the exact analytical calculations for heavy quarkonium production in the QCD perturbation theory in the limit of small m^2/s ratio and nonrelativistic potential model [9,10,11]. In ref.[12] the diquark cc momentum spectrum has been considered to be equal to that of heavy vector quarkonium $(c\bar{c})$[1]

$$D_{c\to cc}(z) = \frac{2}{9\pi}\frac{|R_{cc}(0)|^2}{m_c^3}\alpha_s^2(2m_c)F(z)\;, \tag{1}$$

where

$$F(z) = \frac{z(1-z)^2}{(2-z)^6}(16 - 32z + 72z^2 - 32z^3 + 5z^4) \tag{2}$$

and $R_{cc}(0)$ is a radial wave function of the bound diquark at the origin.

Let us note that identical quarks cc in the colour antitriplet state can only have symmetrical spin wave function in the S-wave, i.e. they must be

[1] In ref. [12] there is a wrong additional factor 2.

in the state with the total spin $S = 1$. The normalization of the fragmentation function $D_{c\to cc}(z)$ is determined by the model dependent value of $R_{cc}(0)$. In ref.[12] a rather rough approximation with the Coulomb potential in the system of heavy quarks has been used. This factor gives noticeable uncertainty in the estimation of the $\Sigma_{cc}^{(*)}$ yield. Moreover, expression (1), obtained in the scaling limit $m^2/s \to 0$, is unsuitable for the estimations of the $\Sigma_{cc}^{(*)}$ production at a B-factory, where the m^2/s ratio is not small.

Earlier, we have proposed another method to estimate the production of the hadrons, containing two heavy quarks on the basis of the quark-hadron duality [9,10].

3 Calculations under quark-hadron duality

The production cross-section of the B_c-meson S-wave states at the Z^0-boson pole, calculated in the fragmentation model (1) [9,10,11], is in a good agreement with the cross-section estimations of the quark pair $(\bar{b}c)$ production in the colour singlet state with small invariant masses

$$m_b + m_c < M(\bar{b}c) < M_{th} = M_B + M_D + \Delta M \;, \qquad (3)$$

where $\Delta M \simeq 0.5 \div 1$ GeV.

In the same range of duality (3) the (bc)-"diquark" production cross-section is approximately equal to that of $(\bar{b}c)$-pair. Selecting the colour antitriplet state (bc) by multiplying by the factor $2/3$, we have obtained the estimation of the $\Sigma_{bc}^{(*)}$ and Λ_{bc}-baryon production cross-sections on the level $\sigma(\Sigma_{bc}^{(*)},\ \Lambda_{bc})/\sigma(b\bar{b}) \simeq 6\cdot 10^{-4}$, i.e. 6 times greater than the estimate made in ref. [12] for the production of $1S$-states. This difference is caused by the fact that, first, the contribution of the higher (bc)-diquark nS-, nP-levels must be taken into the account and, secondly, the strong suppression is determined by the small value of $R_{bc}(0)$.

Let us consider the $\Sigma_{cc}^{(*)}$-baryon production at the energy of the B-factory ($\sqrt{s} = 10.58$ GeV). Note once more that expression (1) may not be used at the given energy because the power corrections over M^2/s are substantial. The method of calculations in the leading order of the QCD perturbation theory has been proposed by us in [9].

In the method of the quark-hadron duality the cross-section for the associated production of the quarkonium bound states can be estimated using

Table 1: The $\eta(\psi)$-meson production cross-sections in e^+e^- annihilation at the B-factory.

state	$\eta_c(1S)$	$\psi(1S)$	$\eta_c(2S)$	$\psi(2S)$
σ, pb	0.025	0.055	0.003	0.010

the formula

$$\sum_{nL,J} \sigma(e^+e^- \to (nL(c\bar{c})_J) + c + \bar{c}) = \int\limits_{m_0}^{M_{th}} \frac{d\sigma(e^+e^- \to (c\bar{c})_{singlet} + c + \bar{c}}{dM_{c\bar{c}}} dM_{c\bar{c}} \tag{4}$$

where $m_0 = 2m_c$ — kinematical threshold of $(c\bar{c})$-pair production, $M_{th} = 2M_D + \Delta M$, $\Delta M \simeq 0.5 \div 1$ GeV.

In Table 1 the results for the numerical calculations of the QCD perturbation theory diagrams are presented for the production of the bound $1S$- and $2S$-levels of charmonium at the energy $\sqrt{s}$=10.58 GeV and α_s=0.2. The values of the radial wave functions at the origin $R_{nS}(0)$ have been determined from the experimental data on the lepton decay widths of charmonia $\psi(nS)$ [14]. As it is evident from Table 1, below the threshold for the decay into $D\bar{D}$ mesons the sum over the S-wave states of charmonia is equal to

$$\sigma(\Sigma\eta_c, \psi) = 0.093 \text{ pb}\,. \tag{5}$$

Note that the ratio of the vector and pseudoscalar state yields at the energy $\sqrt{s}$ = 10.58 GeV is equal to $\omega_V/\omega_P \simeq 2.2$ in contrast to the value $\omega_V/\omega_P \simeq 1$ obtained in the fragmentation mechanism [12].

Our estimations of the integral in the r.h.s. of expression (4) give

$$\sigma_{c\bar{c}}(\Delta M = 0.5 \text{ GeV}) = 0.093 \text{ pb}\,, \tag{6}$$

$$\sigma_{c\bar{c}}(\Delta M = 1 \text{ GeV}) = 0.110 \text{ pb}\,, \tag{7}$$

where we set m_c=1.4 GeV.

From equations (5) and (6) it follows, that the relation of the quark-hadron duality (4) is well satisfied for the bound states of the $(c\bar{c})$-system.

The distributions over the invariant mass of the $c\bar{c}$- and cc-pair are presented on Figs. 1a and 1b, respectively. From these figures one can see that these distributions coincide with each other in the region of small invariant masses. Hence, in the same duality region, the estimates of the $(c\bar{c})$-pair and (cc)-"diquark" cross-sections are approximately equal to each other, so that

$$\sigma_{cc}(\Delta M = 0.5 \text{ GeV}) = 0.086 \text{ pb}\,, \tag{8}$$

$$\sigma_{cc}(\Delta M = 1 \text{ GeV}) = 0.115 \text{ pb}\,. \tag{9}$$

Selecting the antitriplet colour state, one can obtain the total $\Sigma_{cc}^{(*)}$-baryon production cross-section

$$\sigma(\Sigma_{cc}^{(*)}) \simeq (70 \pm 10) \cdot 10^{-3} \text{ pb}, \tag{10}$$

thus the relative number of double charmed baryons is equal to

$$\sigma(\Sigma_{cc}^{(*)})/\sigma(c\bar{c}) \simeq 7 \cdot 10^{-5}. \tag{11}$$

For the luminosity $L = 10^{34}\text{cm}^{-2}\text{s}^{-1}$ the number of events with the $\Sigma_{cc}^{(*)}$ production is equal to $N(\Sigma_{cc}^{(*)}) \simeq 7 \cdot 10^{3}$ per year, so it is by two orders of magnitude greater than the yield of the $\Sigma_{cc}^{(*)}$ baryons at LEP.

The distribution over the (cc)-diquark momentum at the asymmetric collider at KEK [13] (8×3.5 GeV) is presented on Fig. 2.

4 Conclusion

In the present letter we have made exact calculations of the double charmed $\Sigma_{cc}^{(*)}$-baryon production in the leading order of QCD perturbation theory and on the basis of the quark-hadron duality. We present the $\Sigma_{cc}^{(*)}$ production cross-section at the energy $\sqrt{s} = 10.58$ GeV of the B-factory, where the fragmentation formula [12] is not applicable.

The main theoretical uncertainty in the estimations for the production cross-section of the double charmed baryons is related with the description of the process for the heavy (cc)-diquark hadronization. First of all, a considerable fraction of the diquarks (1/3) is produced in the colour sixtet state and can fragment into both the exotic four quark states $(cc\bar{q}\bar{q})$ and the DD-meson pair. As in ref. [12] we assume that colour antitriplet state hadronizes

into the $\Sigma_{cc}^{(*)}$-baryon with 100% probability. Thus, at the B-factory one could expect 10^4 events per year of the $\Sigma_{cc}^{(*)}$-baryon production at the luminosity $L = 10^{34}$ cm^{-2}s^{-1}.

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Figure Captions

Fig.1 The distributions over: a) the invariant mass $M_{c\bar{c}}$ of $c\bar{c}$-pair,
b) the invariant mass M_{cc} of cc-pair.

Fig.2 The distribution over the (cc)-diquark momentum.